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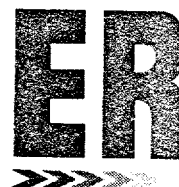
**Monitoring and Modeling Contaminated
Sediment Transport in the
White Oak Creek
Watershed**

Thomas A. Fontaine

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Environmental Restoration Division
ORNL Environmental Restoration Program

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in the White Oak Creek Watershed**

Thomas A. Fontaine

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Author Affiliation

**T. A. Fontaine is a member of the Environmental Sciences
Division of Oak Ridge National Laboratory, Martin Marietta
Energy Systems, Inc.**

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EXECUTIVE SUMMARY

Over the past 47 years, operations and waste disposal activities at Oak Ridge National Laboratory have resulted in the contamination of the White Oak Creek drainage system. The contaminants presenting the highest risk to human health and the environment are particle reactive and are associated with the soils and sediments in White Oak Creek. During floods, the erosion of these sediments results in the transport of contaminants out of the catchment into the Clinch River. A long-term strategy is required to monitor the movement of contaminated sediments and to predict the transport of these sediments that could occur during major floods. A monitoring program will provide the information required to (1) evaluate the existing off-site transport of contaminated sediments, (2) evaluate the need for short-term control measures, (3) set priorities for remediation of contaminated areas in White Oak Creek, (4) verify the success of completed remedial actions intended to control the movement of contaminated sediments, and (5) develop a computer model to simulate the transport of contaminated sediments in White Oak Creek. A contaminant-transport model will be developed to (1) evaluate the potential for the off-site transport of contaminated sediments during major floods, (2) develop long term control measures and remediation solutions, (3) predict the impact of future land-use changes in White Oak Creek on the transport of contaminated sediment. This report contains a plan for the monitoring and modeling activities required to accomplish these objectives.

1. INTRODUCTION

Over the past 47 years, operations and waste disposal activities at Oak Ridge National Laboratory (ORNL) have resulted in the release of diverse contaminants into the White Oak Creek (WOC) drainage system, which includes WOC and tributaries, White Oak Lake (WOL), White Oak Creek Embayment (WOCE), and the floodplains in the watershed. The contaminants presenting the highest risk to human health and the environment are particle reactive and are associated with the soils and sediments in the floodplains and channels of this drainage system. During floods, the erosion and resuspension of these soils and sediments results in the transport of contaminants within the catchment and out of WOL into the WOCE and Clinch River. A Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) time-critical response has recently addressed uncontrolled contaminated sediments in the WOCE. The contaminant inventory in WOCE is small compared with that of the remainder of the drainage system. Therefore, a long-term strategy must be developed for monitoring the release of contaminated sediments from WOC under existing conditions as well as predicting the transport of contaminated sediments that could be expected during extreme floods and future land-use changes. These efforts are needed (1) to control the movement and release of contaminated sediment from the watershed, (2) to assess the risk to health and the environment associated with the Waste Area Groupings (WAGs) in the WOC catchment, and (3) to guide the remedial activities required in the next decade to clean up the WAGs in WOC.

This report contains a plan for the collection of data and for the prediction of contaminated sediment transport required to accomplish these objectives. This is a general plan for the monitoring and modeling of contaminated sediment transport in the entire WOC catchment. Parts of the plan have already been incorporated into several activities conducted in the WOC catchment by the Environmental Restoration (ER) Program at ORNL. For example, the WAG 2 Remedial Investigation (RI) plan (Boston, et al., 1991) and the Environmental Restoration Monitoring and Assessment (ERMA) report (Clapp, et al., 1991) contain specific sampling, analysis, and modeling objectives based on the general strategy presented in this report. The planned activities discussed in this report have also been coordinated with the ER Program that is evaluating the impact of WOC on the Clinch River and other downstream locations (CRRFI, 1990) and will also be coordinated with ER activities at other WAGs in the WOC catchment (e.g., WAGs 1, 5, and 6). In addition to specific applications in WOC and immediately downstream of the WOC catchment, the results of the monitoring and modeling activities planned as part of this project will be useful to other catchments at ORNL and at other Department of Energy facilities where contaminated sediments exist.

2. CONTAMINATED SEDIMENT TRANSPORT IN WHITE OAK CREEK

Contaminants in surface water can be categorized as either particle-reactive or soluble based on their partitioning between the solid and liquid phase. Contaminants that remain in solution in streamflow can be transported through small catchments such as WOC within a relatively short time and may be rapidly diluted. In contrast, particle-reactive contaminants become associated with soil and sediment particles that may remain in the watershed for long periods. Long residence times allow these contaminants to accumulate until high concentrations exist in floodplain soils and lake and channel sediments. Unless these soils and sediments are disturbed during construction projects or are removed as part of a remediation activity, the contaminated material will remain in place until a sufficiently large flood erodes or resuspends the soil and sediment, resulting in a significant amount of contamination moving within and out of the catchment. For this reason a primary pathway for off-site contamination in WOC and many other DOE sites is the surface water system.

This report outlines a strategy for (1) developing a monitoring program to measure sediment flux during floods, (2) evaluating the existing probability of off-site transport of contaminated sediments, and (3) developing a model for predicting and managing contaminant transport during moderate to extreme floods under existing and future land-use conditions. The first step in managing the off-site transport of contaminated sediments is to measure the existing movement of particle-reactive contaminants within and out of the WOC catchment. Sediment transport increases exponentially with increasing discharge, therefore the monitoring system must be accurate over a range of discharges during moderate to extreme floods. Streamflow and water quality parameters are currently measured at White Oak Dam (WOD) and at several other sites within the WOC watershed. However, this system was not intended to monitor contaminant or sediment transport in detail during floods. Therefore, one objective of a monitoring strategy for evaluating the existing contaminant transport in WOC will be to develop a system that accurately measures the discharge of streamwater and the transport of sediment and contaminants for a wide range of streamflow conditions.

Measurements of the movement of contaminated sediments under existing conditions will be used to evaluate the potential for contaminant transport through WOC and out of the catchment into the Clinch River. This information can be used to determine if interim corrective measures (ICMs) are required and to rank WAGs in WOC for long-term remedial activities. In addition, data gathered during the first year or two of monitoring activities will be used to develop the transport model and to design the comprehensive sampling and analysis program required for the application of the model. Specific information on how the monitoring will be accomplished is presented in Section 3.

A second step in the management of off-site contaminant transport is to predict the erosion and resuspension of contaminated sediment in the WOC watershed as a result of moderate to extreme floods in the future. This information is required to predict the impact of these sediments on human health and the environment. This objective requires the ability to predict the movement of sediment and particle-reactive contaminants for a range of floods, including floods much greater than those observed in the Oak Ridge area during the last 20 years.

Possible approaches for determining the transport of contaminated sediments during moderate to extreme floods include (1) measurement by direct observation during a major flood, (2) estimates based on extrapolation of observations made during smaller floods, or (3) predictions using a computer model. The short time frame of this project and the lack of a reliable, comprehensive database restrict the possibility of either direct observation during a major flood or simple extrapolation from small floods in WOC. Information based on direct observation of transport during moderate to extreme floods is usually not available unless a long, comprehensive record of data has been kept (e.g., 50 to 100 years of record) because these events are so infrequent. Simple extrapolation from observations of the transport of contaminated sediments during small floods cannot be used to estimate the transport during larger floods because of the number of factors causing variability in transport processes. For example, even among floods with similar discharges, the concentration of contaminants and sediment in streamflow varies with supply of sediment and contaminants, intensity of precipitation, and time of year. Even larger variation in contaminated sediment transport is expected when floods of different magnitudes are compared because different source areas and physical processes are involved. For example, as discharge increases and water levels rise, new sources of contaminated sediments in channel banks, floodplains, and hillslopes become vulnerable to erosion. In addition, rates of erosion and scour of soil and sediment deposits increase with increasing flow velocities. Therefore, the unpredictable nature of the factors controlling the movement of contaminated sediment during floods makes it difficult to extrapolate observations during small events (e.g., a 5-year flood) to estimate the response during medium to extreme events (e.g., a 50-year flood to events exceeding the 100-year flood).

Instead of using direct observation or simple extrapolation, the transport of sediment and contaminants during larger floods in WOC must be predicted using computer models. A sediment transport model can be designed and calibrated for the anticipated range of floods so that the physical processes controlling sediment movement are adequately simulated for both the small, observed floods and the larger, hypothetical floods. Such a model can also predict water levels for larger floods so that the supply of contaminated sediment available for erosion or scour is accurately represented.

A computer model also provides more flexibility for analyzing the impact of large floods compared to an approach based on direct observation or simple extrapolation. Transport during hypothetical floods (e.g., a 50-year to 100-year event) can be simulated using appropriate values of rainfall, antecedent soil moisture, and other input data. Data regarding land-use conditions can be modified to represent existing as well as expected site conditions in the WOC watershed. For example, the impact of remedial action projects in the near future can be simulated by adjusting data related to physical catchment characteristics and sources of contaminants and sediment.

A long term comprehensive database is required to develop and apply this type of model. The description of the necessary data and the monitoring program that will be used to collect this data are presented in Sect. 4.

3. MONITORING CONTAMINATED SEDIMENT TRANSPORT IN WHITE OAK CREEK

The transport of contaminated sediment in WOC will be measured at seven monitoring stations. The stations will initially be located at the key sites shown in Figure 1. The four primary stations, located at WOD, the weirs just upstream of the confluence of WOC and Melton Branch tributaries, and on WOC several hundred meters downstream of the main ORNL plant area, will remain in place for the duration of the monitoring and modeling programs. These stations will provide information on the movement of contaminated sediments between major subcatchments in the WOC catchment. In addition to the four primary stations, three secondary stations will be used at five or more locations in WOC. Each secondary station will be established at a specific site for approximately 6 to 12 months in order to develop an estimate of the sediment and contaminant contributions from minor subcatchments in WOC. Once a secondary station has monitored several floods at one location, the monitoring equipment will be relocated to a new temporary site.

3.1 MEASURING SEDIMENT TRANSPORT

At each station, samples of suspended sediment and bedload will be collected using established sampling techniques described in ASCE (1975), Guy and Norman (1982), Edwards and Glysson (1988), and ASTM (1990a). Suspended sediment will be collected using both automatic and manual sampling methods. Automatic sampling will be required for several reasons. Floods in WOC resulting from intensive rainfalls can have a very short time-to-peak because of the small catchment area (16 km^2). Under certain conditions the peak stream discharge may occur in less than one hour of the onset of rainfall; in this situation it would be difficult to collect manual samples at seven stations. In addition to stream discharge, the discharge of sediment and contamination usually increase rapidly during the rising limb of a storm hydrograph, requiring frequent samples shortly after rainfall begins. Automatic sampling will also be required when field conditions are too hazardous for manual sampling (e.g., during extreme floods and when floods occur during darkness).

Automatic sampling systems will be programmed to collect suspended sediment whenever streamflow exceeds predetermined discharges at each station. This approach has been successfully applied at two field-test sites in WOC during the period of March to September, 1991 using ISCO pumping samplers connected to stage indicators. Automatic samplers withdraw streamwater and suspended sediment from a fixed point in the stream (e.g., 1 ft above the streambed, at the centerline of the channel). The use of a fixed-point withdrawal can lead to uncertainty in calculating sediment transport because the concentration of suspended sediment can vary significantly both horizontally and vertically across the stream channel.

To minimize potential uncertainty associated with a fixed-point withdrawal, manual samples will be collected using standard methods to determine the average suspended sediment concentration across the entire channel cross-section at the same time that automatic samples are taken. Manual sampling equipment will include the US DH-48, US DH-76, and US D-74 samplers. These devices have been developed and tested by the

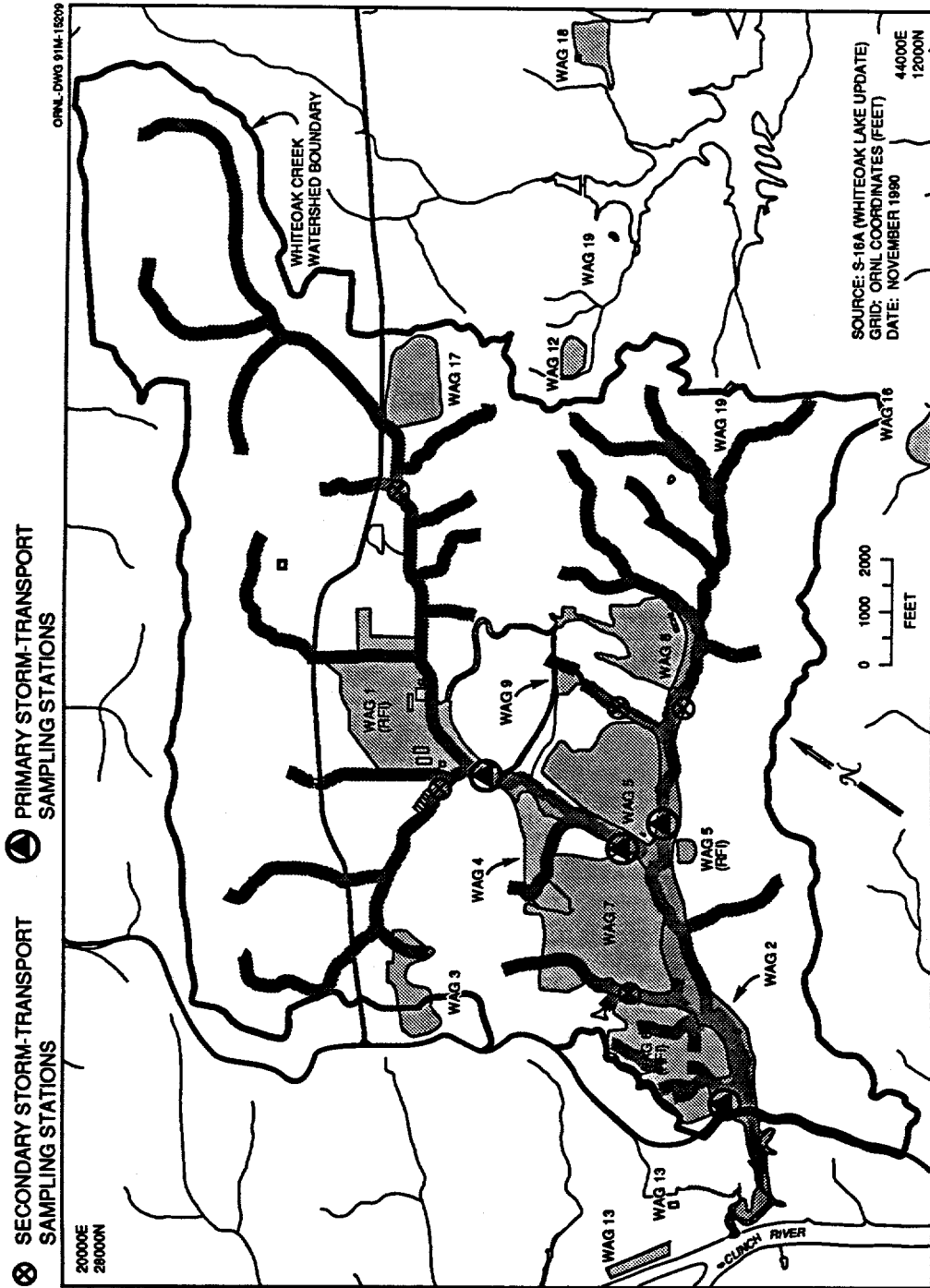


Fig. 1. Location of Monitoring Stations

Federal Interagency Sedimentation Project and are widely used by the U. S. Geological Survey and several other Federal agencies involved with the routine collection of sediment data (Edwards and Glysson, 1988). After concurrent automatic and manual samples have been collected for a range of discharges, a relationship will be developed to transform data from automatic samples taken at a single point in the channel into an average value of sediment concentration for the channel cross section.

In addition to suspended sediment sampling, data will be collected to measure bedload transport at each monitoring station. Bedload (coarser sediment that rolls or bounces along the streambed) will either be measured directly (e.g., using a sampler similar to a Helley-Smith device (Helley and Smith, 1971) and an approach similar to that described in Emmett (1981), or will be calculated using bedload transport formulas and samples of stationary bed material (ASCE, 1975; ASTM, 1990b).

3.2 STREAM DISCHARGE MEASUREMENTS

Accurate measurements of streamflow discharge taken concurrently with sediment samples are critical for reliable calculation of sediment and contaminant transport. The existing network of flow-monitoring stations in WOC is not capable of providing accurate discharge measurements during some of the larger floods expected during the monitoring program for contaminated sediment transport. The existing discharge measurement system is being upgraded by the Environmental Surveillance and Protection Section with assistance from the Environmental Restoration Monitoring and Assessment (ERMA) Program (Clapp, et al., 1991) to improve measurements during floods. In the meantime, discharge measurements will be evaluated for accuracy and corrected when necessary to allow the use of data collected from the existing system.

3.3 LAB ANALYSIS

Sediment samples will be analyzed to determine the flux of sediment and particle-reactive contaminants in the major tributaries of the catchment and the total release from WOC during a variety of storms. Samples taken during five of the largest storms in the first year of monitoring will be used for analysis of the physical characteristics of sediment samples and initial screening for contaminants. Particle-size distribution, specific weight, sediment concentration, and other characteristics of suspended sediment and bedload will be determined from samples taken at approximately ten points in time during each flood. Approximately seven of the ten samples selected for lab analysis during each storm will be samples taken during the rising limb of the hydrograph because the concentration of sediment transported during floods often changes most rapidly during this period (Figure 2). Standard methods (e.g., Guy, 1969; ASCE, 1975; ASTM, 1990c) will be used with modifications for the specific field conditions and project objectives in WOC.

Initial screening for contaminants will focus primarily on ^{137}Cs because it is a relatively inexpensive particle-reactive contaminant for which to analyze and because it is common in many of the tributaries in the catchment. For example, of the ten samples selected for lab analysis during each storm at a given station, only three or four samples may be analyzed for

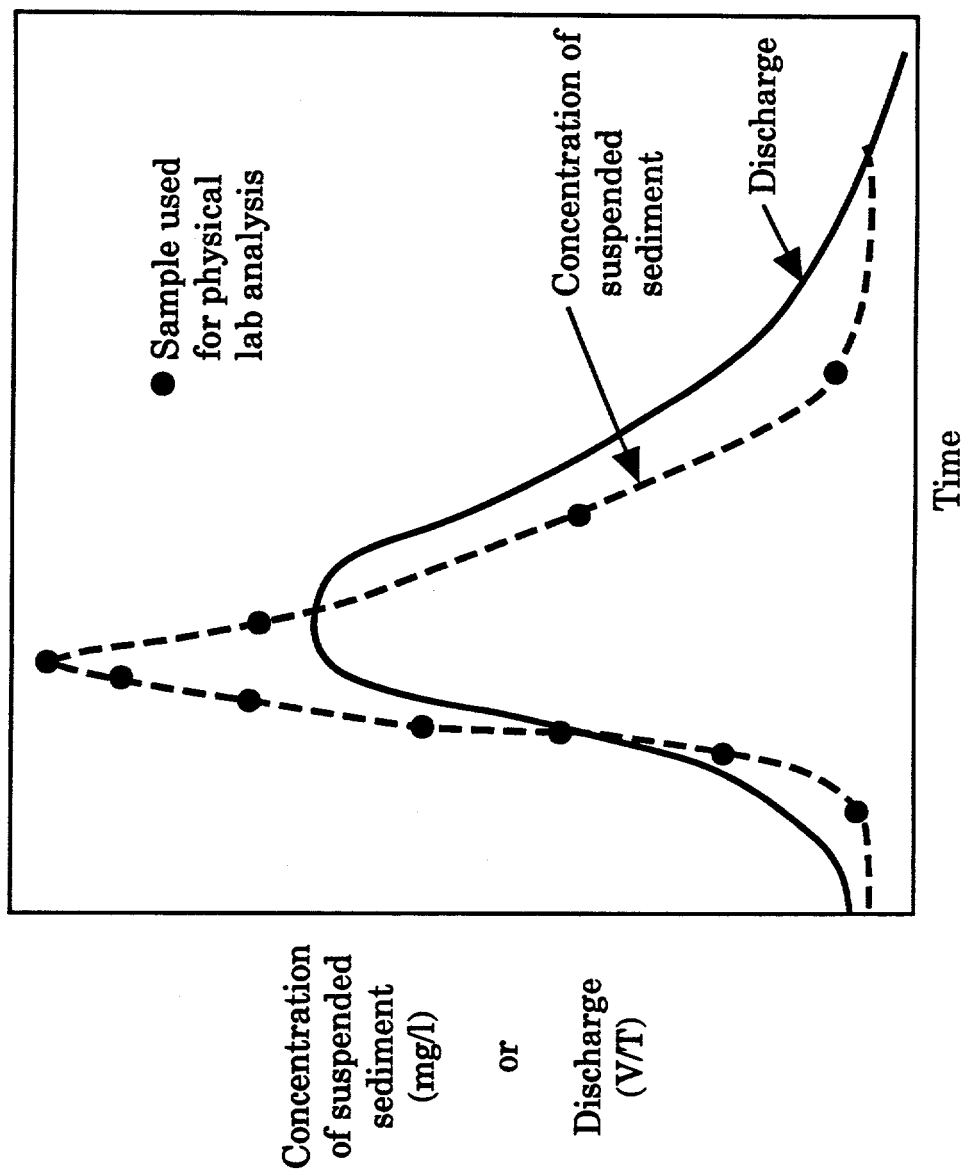


Fig. 2. Distribution of samples used for analysis during a hypothetical hydrograph

¹³⁷Cs. During the initial analyses for ¹³⁷Cs, samples will be screened on a limited basis for other radioactive contaminants and for metallic and organic contaminants using standard methods (e.g., Horowitz, 1985; Kimbrough et al. 1988; ASTM, 1990d). As field and lab procedures become standardized (e.g., as quality control procedures are modified to account for unique conditions at each station, as estimates of uncertainty in field and lab procedures are developed, and as more information about the critical processes involved in the transport of contaminated sediment in WOC becomes available), the lab analysis for contaminants other than ¹³⁷Cs will be extended in terms of types of chemicals analyzed for and number of samples analyzed, and some of the samples will be analyzed for chemical characteristics of sediment.

4. MODELING CONTAMINATED SEDIMENT TRANSPORT IN WHITE OAK CREEK

The development of a computer model for simulating the transport of contaminated sediment in WOC will provide a method of (1) predicting contaminant transport during moderate to extreme floods, (2) developing long-term control measures and remediation solutions and (3) predicting the impact of future land-use changes on the transport of contaminated sediment. The prediction of transport during extreme floods and of the impact of changes in the physical characteristics of the watershed requires a model that simulates the following physical and chemical processes: (1) streamflow generation (i.e., rainfall-runoff processes), (2) channel hydraulics and flood routing, (3) the erosion, transport and deposition of sediment, and (4) the interaction between sediment and contaminants. These processes must be adequately simulated at discharges ranging from a 1-year to at least a 100-year flood. The model should be intended for application to individual hillslopes (e.g., a single WAG) or an entire catchment. A process-oriented model will allow the simulation of the impact on contaminant transport of a hypothetical change in the physical characteristics of a portion of the catchment, such as the installation of an impervious cover over hillslopes in WAG 6 or the widespread removal of vegetation for a new solid waste disposal area.

Process-oriented models require calibration and verification of parameters. During calibration, observed input and output data (e.g., time-series data for precipitation, discharge, sediment load and contaminant concentrations) are used to set values for certain parameters to ensure that the model will accurately simulate the various processes involved. The calibration of the model is then verified by using an independent set of observed input and output data to evaluate the accuracy of the simulated output data. The calibration and verification data available during the first few years of this investigation in WOC will probably be limited to relatively small floods and to the existing land-use conditions. Therefore it is important to select a model that can produce initial results with a limited amount of calibration data, as well as having the potential for improved results as the monitoring program provides additional data in the future.

The *Hydrologic Simulation Program-Fortran* (HSPF) (EPA, 1984) is an example of a good computer model for this application. HSPF has components for streamflow generation, flood routing, sediment transport and contaminant-sediment interaction. This model is appropriate for simulations on both hillslope and catchment scales and provides a balance between a simple empirical model and a complex, physically-based, spatially-distributed model, providing acceptable accuracy for this application without a major investment of resources. HSPF is well documented and is currently being used for a variety of applications at ORNL.

HSPF includes over 50 parameters that describe site-specific conditions and processes that are important to the transport of contaminated sediment. Collecting field data to calibrate 50 parameters is a major task; therefore, a sensitivity analysis will identify the parameters which are most critical for model accuracy under the field conditions in WOC. The data needed to set values for these critical parameters will be obtained by a sampling and analysis program. Values for parameters that are less critical for model accuracy are determined with data from short-term data collection surveys, values found in publications of similar investigations, or the experience of the modeler.

Calibrating and verifying HSPF requires information for hydrologic processes, sediment supply, sediment transport, and contaminant-sediment relationships. Specific types of data are listed in the appendix, and an example of a sampling and analysis plan to develop this database for WAG 2 is given in Boston, et al (1991). The major types of calibration data are briefly described in the remainder of this section.

4.1 HYDROLOGIC DATA

The information required to calibrate the rainfall-runoff processes in HSPF include time-series data for precipitation, stream discharge, soil moisture and potential evapotranspiration, and data for topography, channel geometry, land use, soil characteristics, and vegetation. This type of information is currently available from existing monitoring activities [e.g., the ERMA program (Clapp, et al., 1991) and the Environmental Monitoring and Surveillance Division] and from maps, soil surveys, and field surveys.

4.2 SEDIMENT SUPPLY

Fluvial sediment in WOC is generated by the erosion of hillslopes, floodplain sediments and stream banks, and by the scour of streambeds. The calibration and application of HSPF requires information on processes causing erosion (rainfall and overland flow) and scour (streamflow), and data for the resistance to erosion of various soil types and particle sizes. This information can be collected through field surveys using methods described in Lal (1988) and ASCE (1975).

4.3 SEDIMENT TRANSPORT

Calibrating the sediment transport processes in HSPF requires information on the physical characteristics of sediment and measurements of suspended sediment and bedload during floods in WOC. This information will be available from the monitoring effort described in Section 3. Measurements of critical shear stress values for the deposition and scour of cohesive channel sediments will be required, as well as estimates of the initial storage of gravel, sand, silt and clay in the channel system.

4.4 CONTAMINANT-SEDIMENT RELATIONSHIPS

Information about contaminant sources and the characteristics of contaminants and sediment will be required. Specific sources and accumulation zones of contaminated sediment in much of WOC will be identified in 1992 and 1993 as part of the WAG 2 sampling and analysis effort (Boston, et al., 1991). Information for the critical factors controlling contaminant-sediment interaction (e.g., contaminant chemistry, mineralogy and surface area of particles, organic content of sediments, and water chemistry) will be collected from a review of the literature, field sampling and lab analyses.

4.5 MODEL SIMULATION OF TRANSPORT DURING FLOODS

Although HSPF requires extensive calibration before the simulations can be considered reliable, tentative predictions are possible with a limited amount of calibration data (i.e., after the first year of sampling and analysis required to develop the database for the complete calibration and verification of the model). Results simulated with an uncalibrated model are useful for developing approximate estimates of contaminated sediment transport during floods, for improving our understanding of the transport processes in WOC, and for guiding the sampling and analysis activities required to develop the database for complete calibration. As calibration data become available, these initial estimates become more reliable and the monitoring program can be focused on the data required to reduce uncertainty in the predictions.

The initial calibration of the hydrologic and sediment transport components of HSPF should be possible once the first two years of intensive monitoring are completed. By the time three years of monitoring data are available the contaminant transport components should be initially calibrated as well. At this stage the model will be used for predicting contaminated sediment transport required for initial risk assessment, planning, and estimating the uncertainty in the results. It is expected that after the third year, the number of samples analyzed in the lab can be reduced by concentrating on moderate to extreme floods to gather data to reduce the uncertainty of model predictions during larger events.

Once the hydrologic and transport components of the model have been calibrated and verified, information from the database will be used to simulate contaminated sediment transport during moderate to extreme floods. The input data will consist of hypothetical conditions of precipitation, antecedent soil moisture, land use, and supplies of sediment and contaminants. The magnitude of simulated floods will range between the 5-year event and the 100-year event, with conditions representing existing land-use and contaminant sources. These results will define the contaminated transport associated with a flood of a specified probability, providing information required for risk assessment in the management of WOC. Contaminant transport will also be simulated using anticipated changes in land use that may occur in the near future as waste areas in WOC are opened or closed and as environmental restoration activities are conducted. Estimates of uncertainty in the results will be included in the analysis.

4.6 MODELING FOR EVALUATION OF ALTERNATIVES TO CONTROL OFF-SITE TRANSPORT

Assuming that the probability of off-site contamination justifies consideration of remedial action in WOC, alternative methods for reducing the movement of contamination will be developed. Possible options include (1) no action, (2) restricted access, (3) removal and storage, (4) in situ stabilization, and (5) control of sources and discharges. A modeling program used during the design and planning phases of these alternatives will be useful in the development of detailed designs and in the evaluation of potential hazards that could occur during remediation. After a remedial action plan has been selected for use, a monitoring and modeling program will be required so that documentation of the environmental impact during the construction phase may be accomplished.

4.7 MONITORING AND MODELING TO EVALUATE EFFECTIVENESS OF COMPLETED CONTROL MEASURES

Upon completion of a remedial action alternative, a period of monitoring and modeling will be required to prove that the action has been successful. The critical element in this task will be the availability of a reliable record of contaminant transport before and after the activity. Data should be collected upstream and downstream of sites where remedial activities are expected to occur (e.g., at a minimum, stations are required upstream and downstream of the ORNL main plant area, at the existing discharge monitoring stations just upstream of the confluence of the WOC and Melton Branch tributaries, at WOL dam, and at the point where WOCE meets the Clinch River). The complex hydrology of the WOC system could lead to unexpected responses to remedial action efforts; therefore, it will be important to have a comprehensive, long-term, reliable database that can serve a variety of purposes. In order to provide the best database for comparing conditions before and after remedial action, and to account for the chance of pre-construction monitoring including years with no significant floods, this monitoring should begin as soon as possible.

5. CONCLUSION

The long-term strategy for monitoring and modeling contaminated sediment transport in WOC will produce the information required to monitor, predict, and manage the release of contaminated sediments from WOC under existing and future conditions. This information will be acquired through a long-term monitoring program and the development of a computer model for the transport of contaminated sediments during a range of floods. The monitoring program will involve several years of intensive sampling and analysis of concentrations of sediment and contaminants at a number of locations in the WOC catchment, followed by less intensive monitoring focused on reducing uncertainty during larger floods. The computer model will simulate the transport of contaminated sediment within and out of WOC catchment during floods up to the 100-year event. Existing conditions of land-use and contaminant sources, as well as future conditions during and after construction of control measures, will be analyzed. The results of this project will be important for evaluating the potential for off-site contaminant transport, designing possible alternatives for controlling contaminant transport, and evaluating the effectiveness of completed control measures. The results will apply to the WOC catchment, to the Clinch River ER project, and to other ER projects at ORNL and other DOE sites.

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APPENDIX

Type of Data Required for HSPF

(No distinction has been made between data required to set parameters and data required to calibrate parameters)

- **Rainfall-Runoff Processes** (streamflow generation)
 - precipitation (10 minute intervals if possible)
 - potential evapotranspiration
 - stream discharge hydrographs
 - initial conditions for moisture storage in upper and lower soil zones and in interflow and active groundwater
 - density and type of vegetative cover (hillslope and riparian)
 - root zone depth
 - land use (including retention and detention storage in impervious areas)
 - soil type or permeability, soil temperature
 - catchment area, lengths and slopes of channels and hillslopes
 - roughness coefficients for hillslopes and channels (Manning's n)
 - groundwater levels, hydraulic conductivity of deep groundwater systems
 - depth-volume-surface area relations for channels and lakes
 - backwater profiles for specific discharges (e.g., HEC-2 output)
 - specific weight of streamwater
 - ratio of maximum stream velocity to average stream velocity
- **Sediment Supply** (erosion, scour, and deposition)
 - rainfall intensity, overland flow and initial conditions for surface flow storage (this information is provided from the hydrologic components of HSPF)
 - areas with erosion resistant cover (e.g., vegetation, mulch, erosion protection)
 - supporting soil management practice (the equivalent of agricultural soil management practices that apply to unprotected soil in WOC)
 - factors for the susceptibility for soil detachment and soil matrix scour
 - solids transport capacity of flow over impervious surfaces
- **Sediment Transport During Storms**
 - sediment-discharge rating curves developed from measurements of suspended and bed load during stormflow
 - percent by weight of gravel, sand, silt and clay fractions
 - settling velocities of each size fraction
 - particle density
 - critical shear stress for deposition and scour of silt and clay
 - erodibility coefficient of silt and clay
 - median and 60% grain diameter
 - initial storage of gravel, sand, silt and clay in streambed
 - water temperature
 - hydraulic radius of each channel segment

- **Sediment-Contaminant Relationships**

- "potency factors" : monthly values of the concentration of a contaminant attached to sediment that has been eroded from a pervious or impervious surface (generally a function of the distribution coefficient (K_d) for the contaminant and the grain size and mineralogy of the sediment particle)
- supply of each contaminant to the system (time series of flux entering WOC either adsorbed to sediment or in dissolved phase)
- susceptibility of a contaminant to washoff by overland flow
- concentration of contaminants in sub-surface flow (interflow and groundwater flow)
- transfer rates for adsorption/desorption of contaminants on sediment
- data for heat exchange and water temperature (solar radiation, cloud cover, air temperature, dewpoint temperature, windspeed)
- decay rate (and temperature correction coefficient) for decay of an adsorbed contaminant

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